Land-use modelling by cellular automata

Hansen, Henning Sten

Published in:
NORDGI : Nordic Geographic Information

Publication date:
2006

Document Version
Publisher's PDF, also known as Version of record

Nordic GIS Conference

Helsinki, 2. – 4. October 2006

Land-use Modelling by Cellular Automata

Henning Sten Hansen

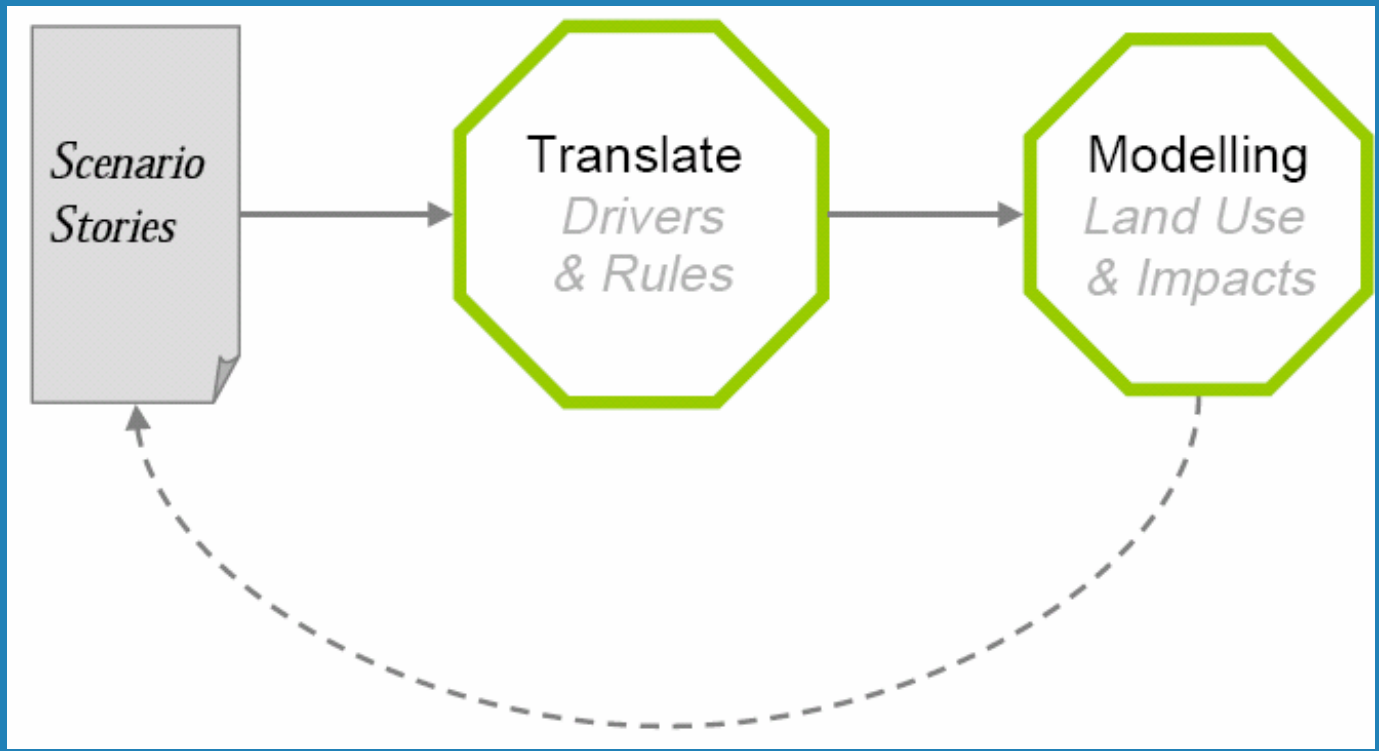
Ministry of Environment
National Environmental Research Institute

AALBORG UNIVERSITY

Overview

- The principles of cellular automata
- Previous CA based land-use studies
- The current model
- Conclusions and further work

From words to models



Cellular Automata - CA

- Introduced in the late fourties abyf John von Neumann and Stanislaw Ulam
- In the late sixties John Horton Conway developed *The Game of Life*
- CA is discrete dynamical systems and is often described as a counter part to partiel differential equations for continuous systems

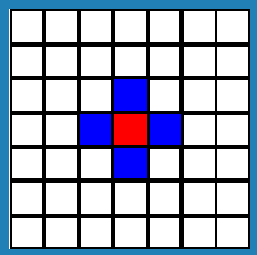
Cellular Automata

The most important properties of a CA system

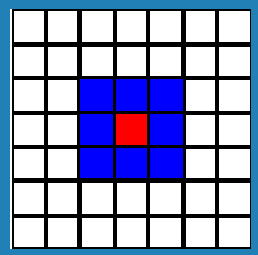
- A regular n-dimensional grid (n is often equal to 1 or 2), where every cell within the system has a discrete state
- A dynamic behaviour, defined by rules describing the state of a cell at the subsequent time on the basis of the state of the neighbouring cells

Local interaction leads to global dynamics

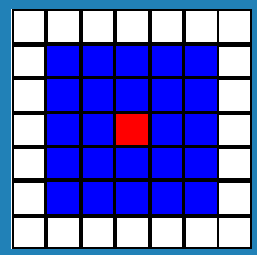
The main principle in CA



von Neumann Neighbourhood



Moore Neighbourhood



Udvidet Moore Neighbourhood

General principles for CA

$S_{ij}(t)$ the state for the cell x_{ij} at the time t

$S_{ij}(t+1)$ the state for the cell x_{ij} at the time (t + 1)

$S_{ij}(t+1) = F(S_{\Omega(i,j)}(t))$

where Ωij represents the neighbouring cells to the cell x_{ij}

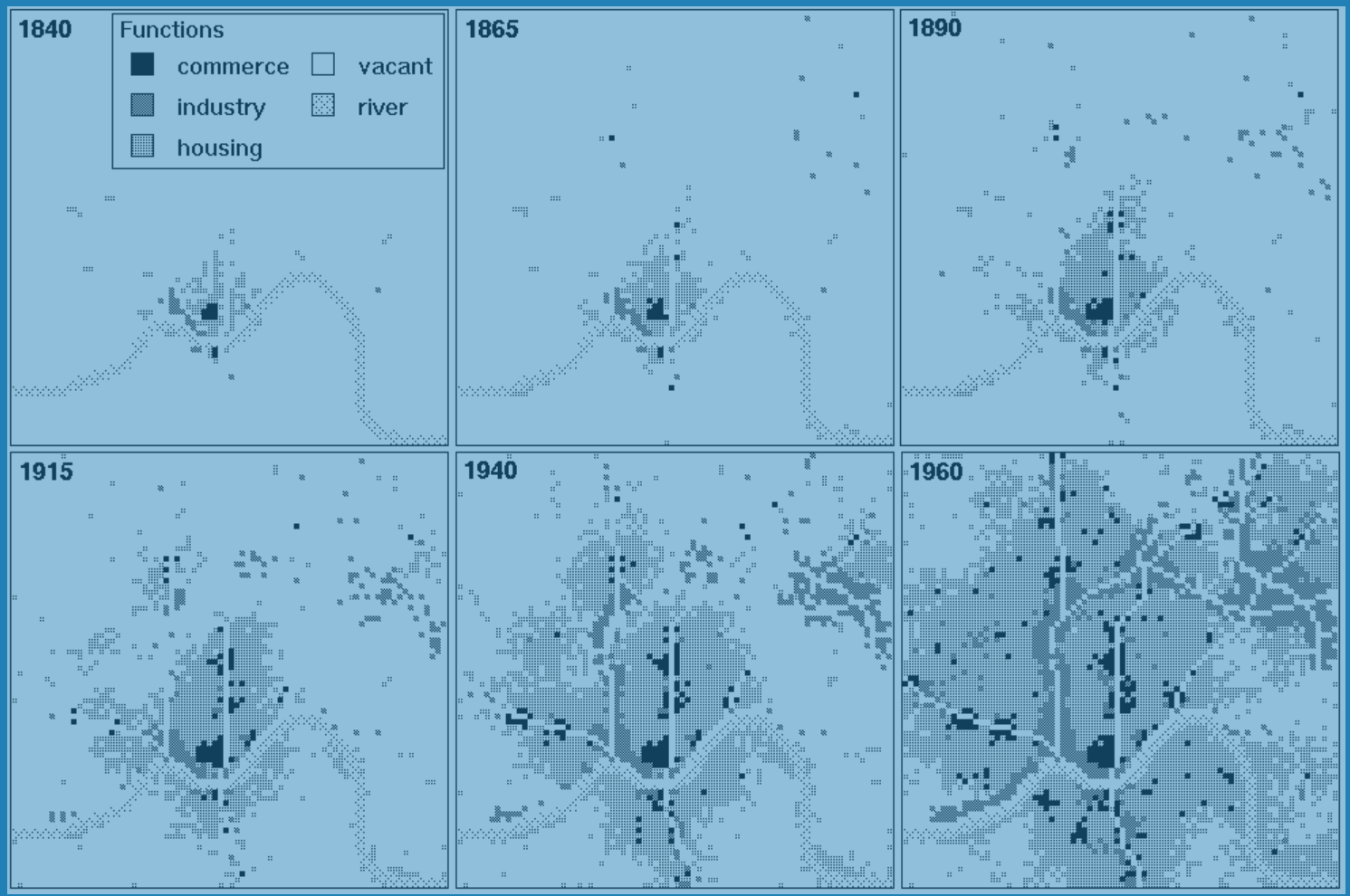
IF

(something happens among the neighbours of the cell)

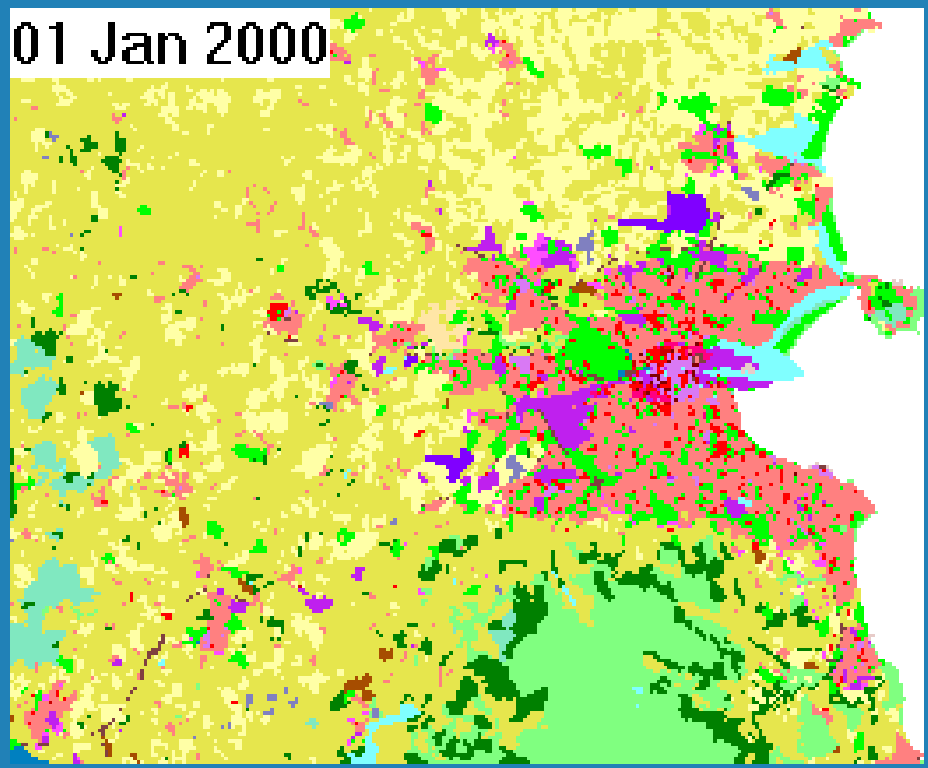
THEN

(the cell will change its state at the next time step)

Cincinnati's development 1840 - 1960



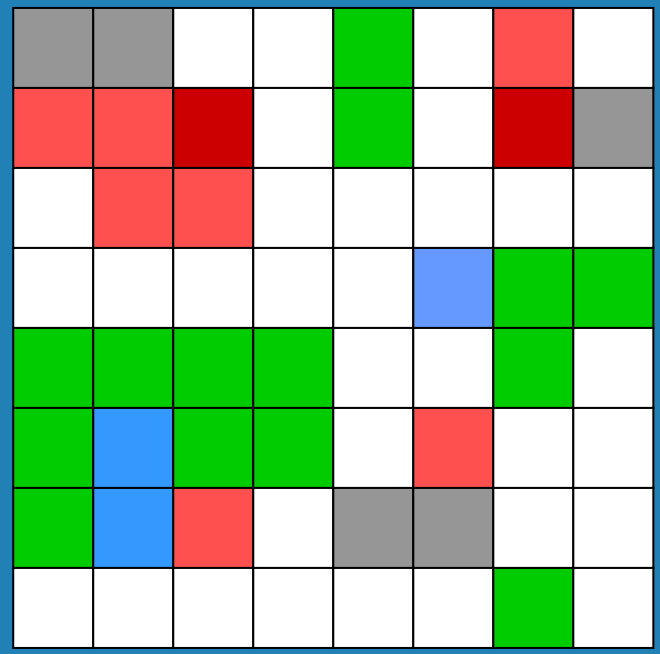
Simulating Dublin's development



The Moland Project)

CA model for land-use dynamics

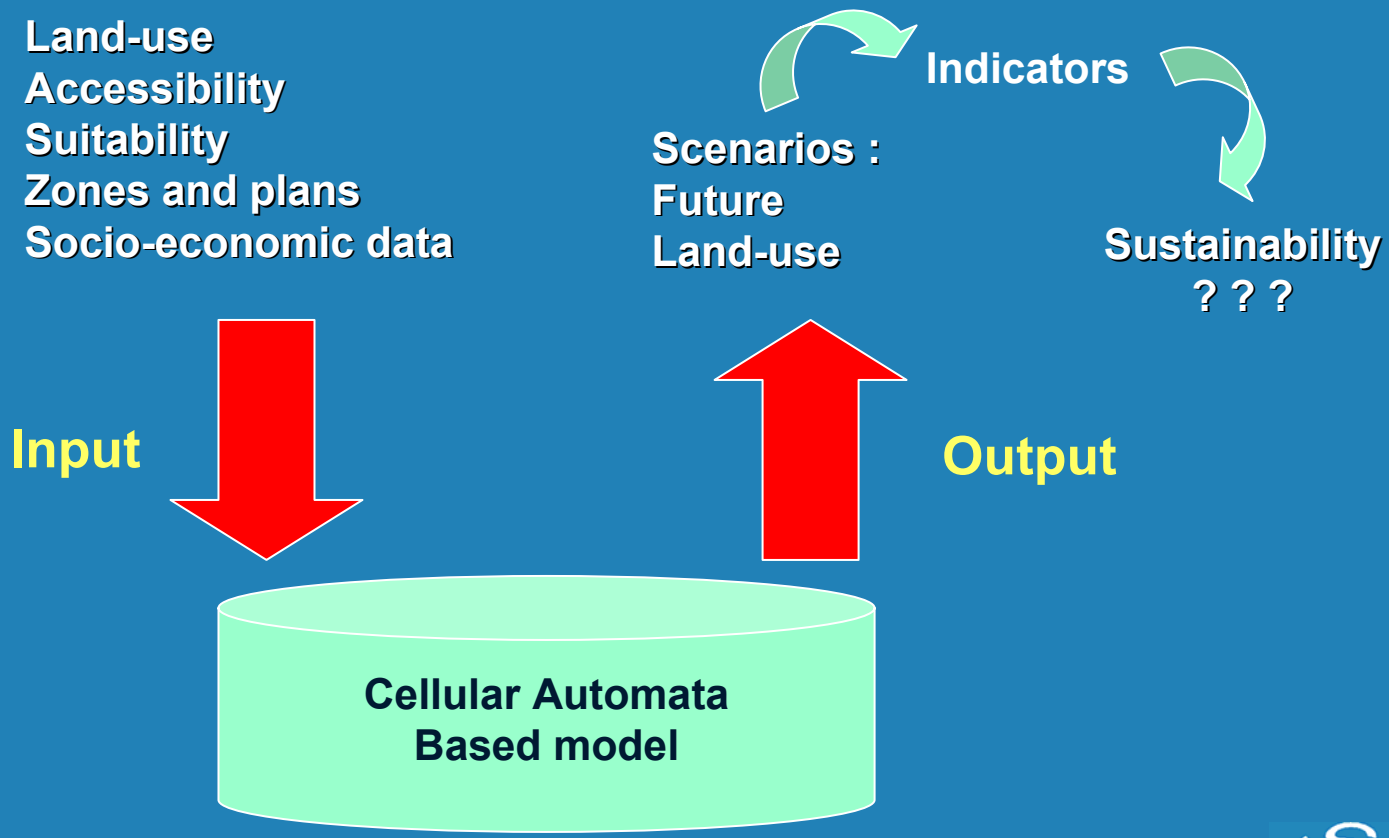
- The *States* represents the various land-use classes
  - Dynamic states
  - Passive states
  - Static features



Residential Industry Forest

Service Arable Lake

The Model

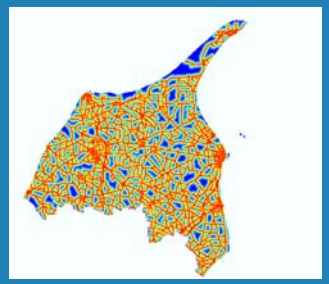

Land-use
Accessibility
Suitability
Zones and plans
Socio-economic data
Input
Cellular Automata
Based model
Output
Scenarios :
Future
Land-use
Indicators
Sustainability
? ? ?

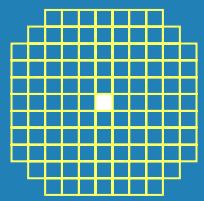
Driving forces

- Spatial planning (environmental legislation, energy policy)
- Demography (population development, migration)
- Values of the society (quality of life, concern about the environment)
- Economic development
- Technological development (information society)
- Environmental impacts (emissions, climate changes)

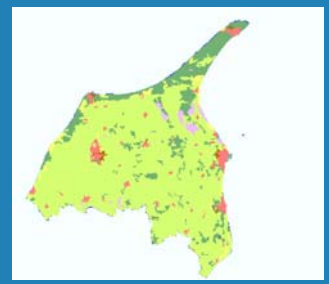
The Model Concept

Accessibility

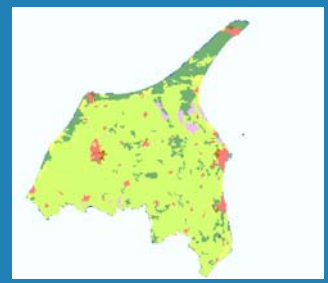




Neighbour effect

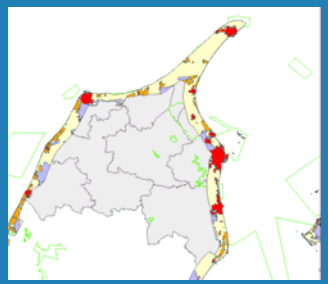


Simulated Land-use 2020

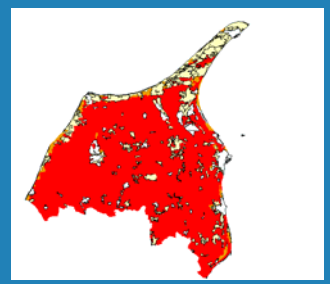


Land-use

Driving Forces



Spatial Planning



Suitability

Calculation the *Neighbourhood effect*

$$R^{t}_{K,x,y} = \sum_{c}\sum_{l} w_{K,L,c} I_{c,l}$$

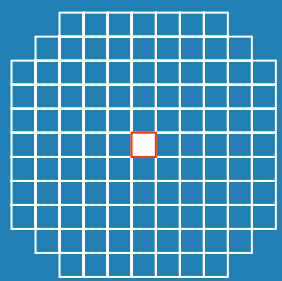
$$R^{t}_{Arealanv,x,y} = \sum FocalSum(Arealanv == n, Weight, Kernel)$$

R_L1(x,y) = FocalSum(LU == 1, WEIGHT, Kernel_L1L1) +
FocalSum(LU == 2, WEIGHT, Kernel_L1L2) . . . .

R_L2(x,y) = FocalSum(LU == 1, WEIGHT, Kernel_L2L1) +
FocalSum(LU == 2, WEIGHT, Kernel_L2L2)

. . . . . .

Etc.



Accessibility

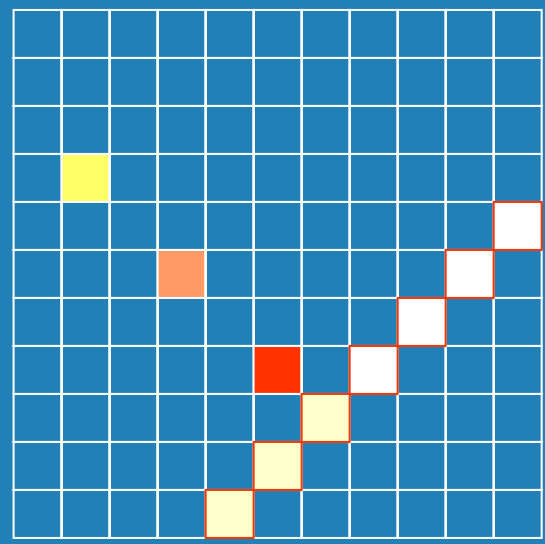
$$A^{t}_{K,x,y} = \frac{1}{1 + \frac{D}{a_K}}$$

A = 1/(1 + √2) = 0,1239

A = 1/(1 + 3√2) = 0,1907

A = 1/(1 + 5√2) = 0,4142

Transport network



How to make the CA model

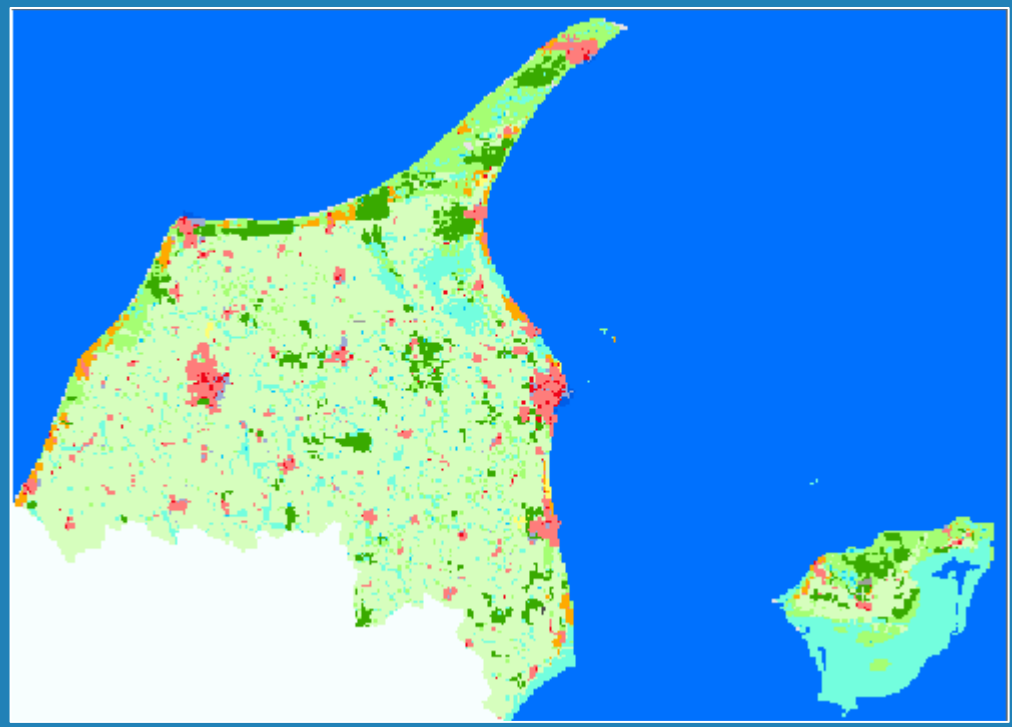
- Decide about the active states, the passive states and the static features
- Decide the spatial resolution of the model
- Obtain minimum 2 land-use maps to do the calibration against the historical development (minimum 10 years between)
- Prepare the land-use data
- Define the distance-decay functions
- Run the model repeatedly and evaluate the effects of the changed rules

Land-use 1990

CORINE 1990

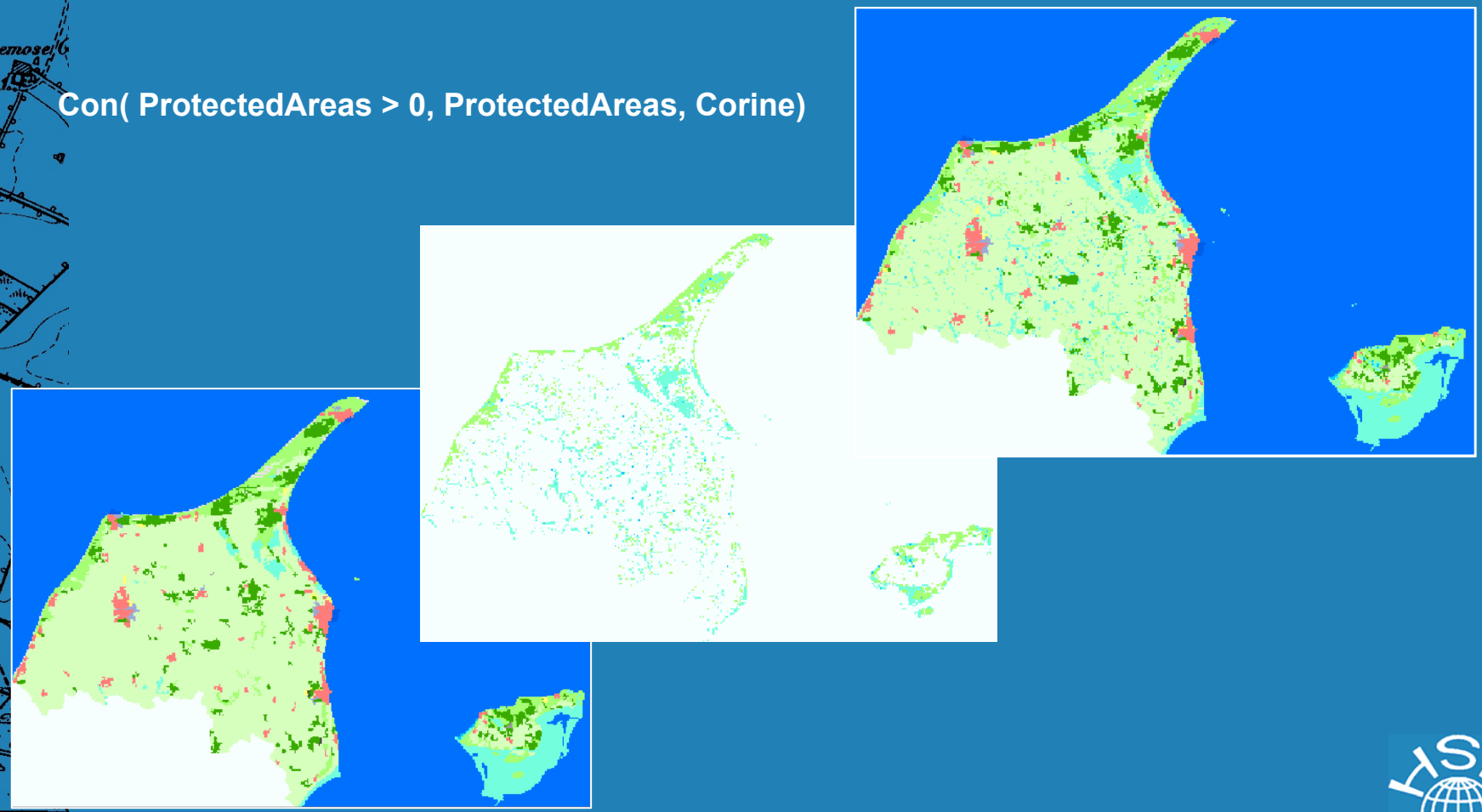
BBR

Protected Nature



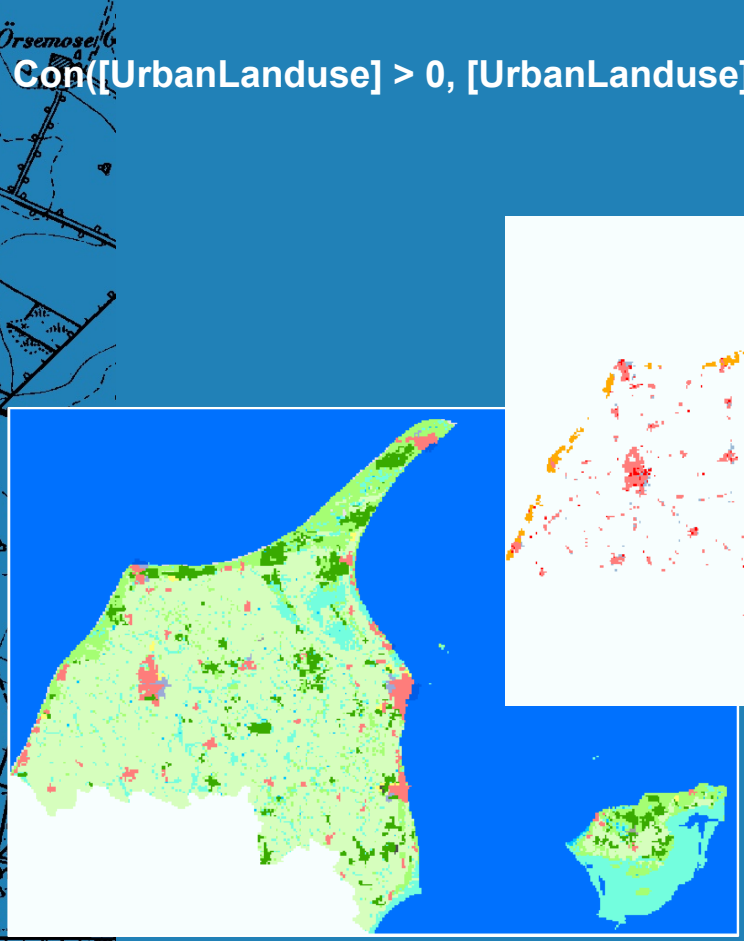
Add Protected Areas

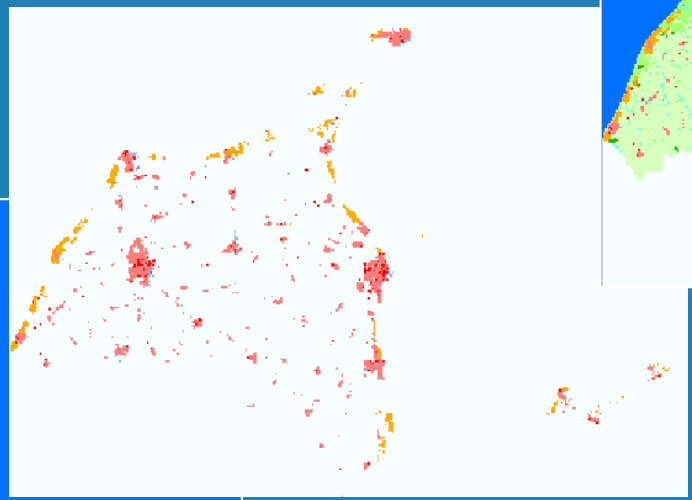
Con(ProtectedAreas > 0, ProtectedAreas, Corine)

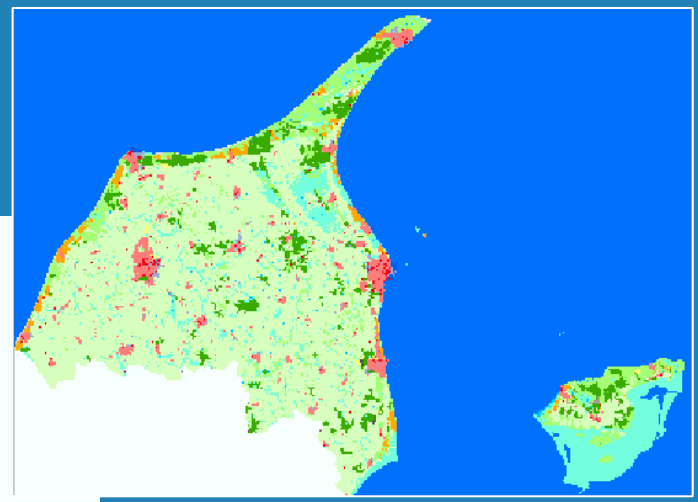


Add urban land-use

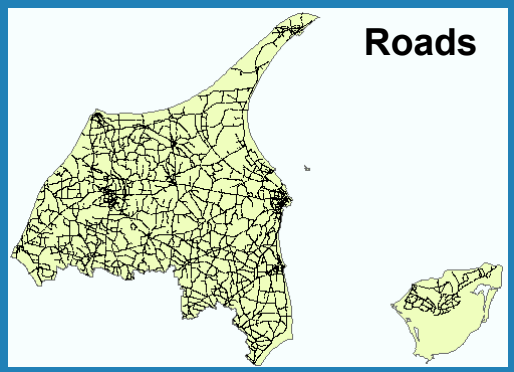
Con([UrbanLanduse] > 0, [UrbanLanduse], [CorinePlus])



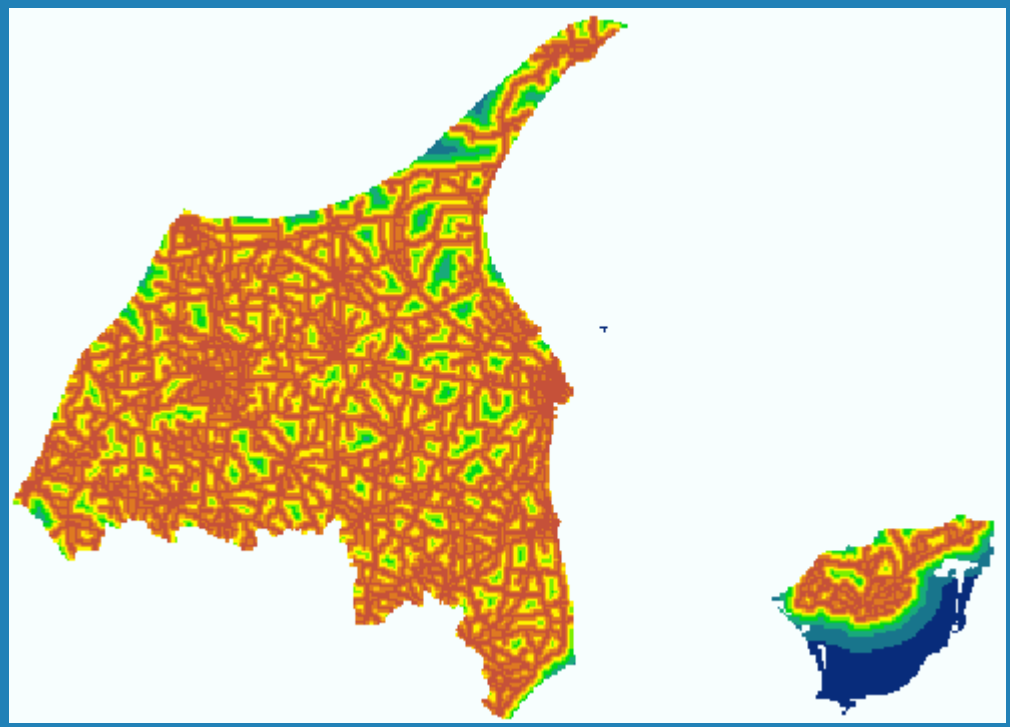




Accessibility



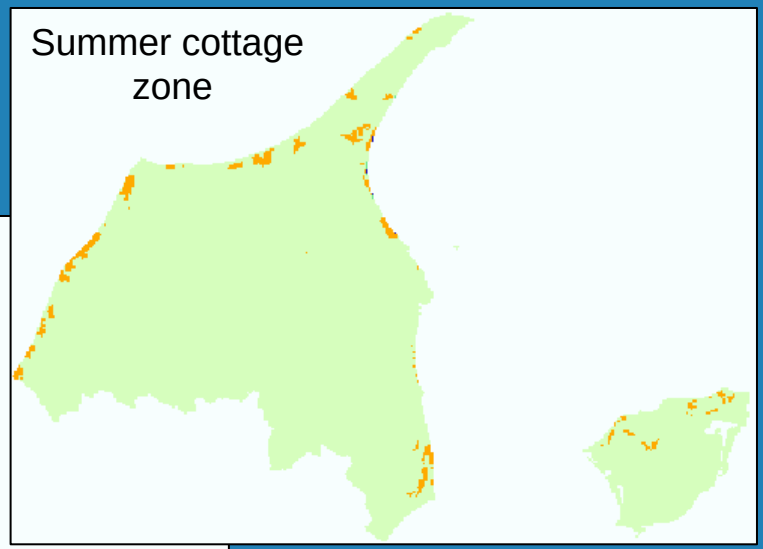
$$A^{t}_{K,x,y} = \frac{1}{1 + \frac{D}{a_K}}$$

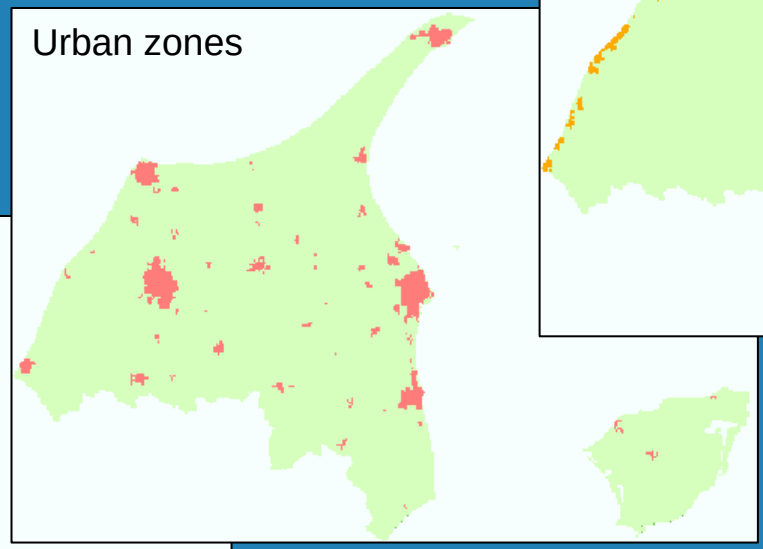


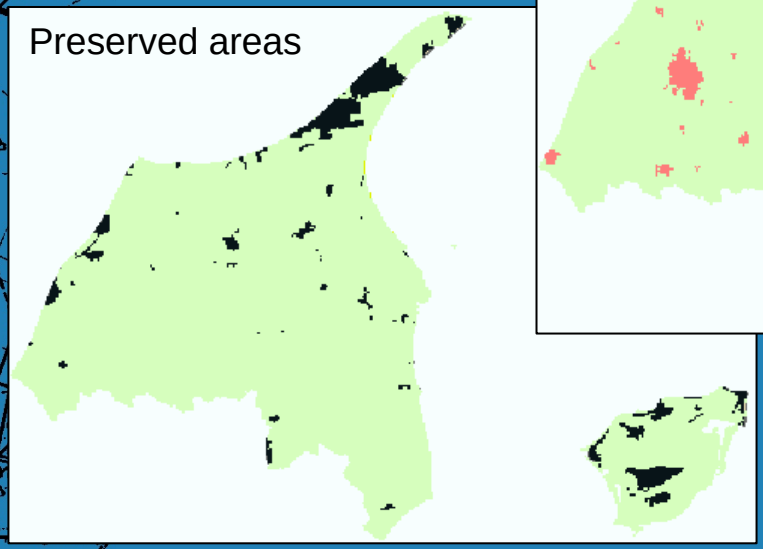
High

Low

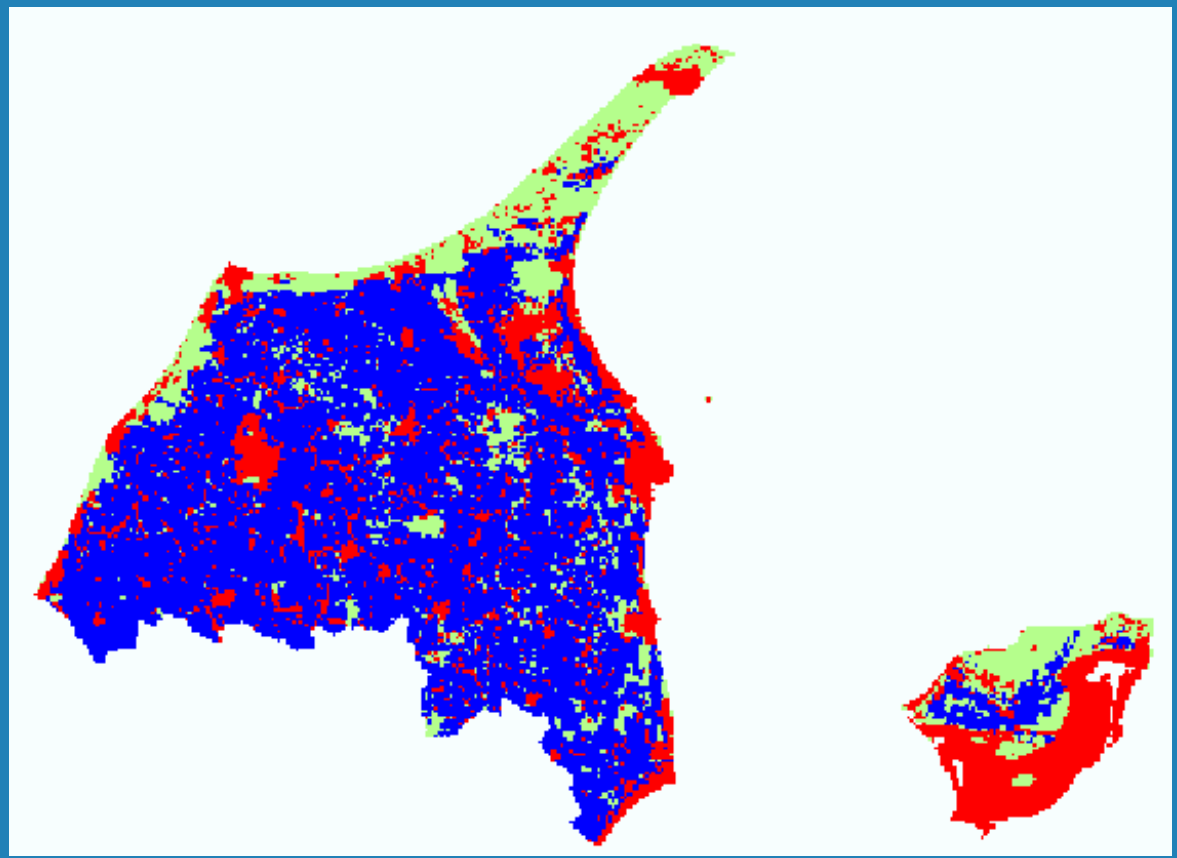
Spatial Planning Zones



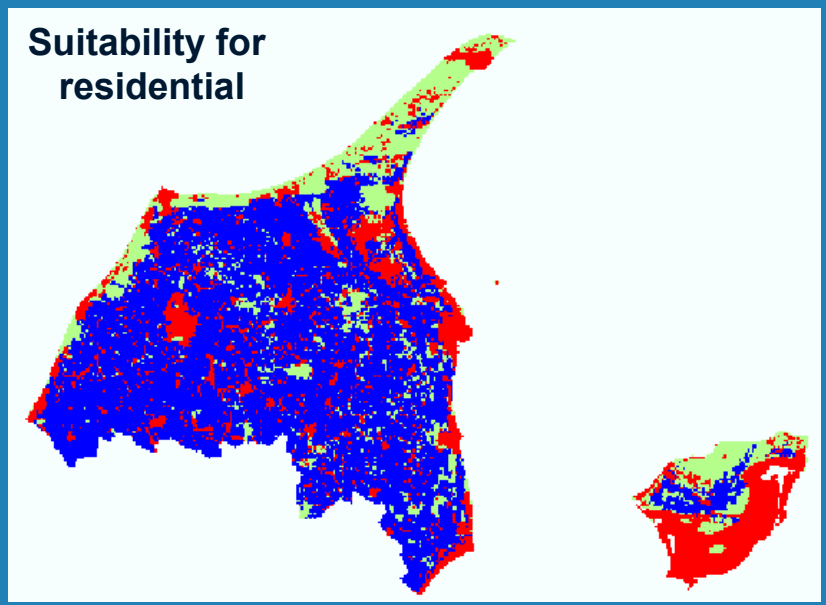




Suitability



Suitability



- Suitability is based on
  - Existing land-use
  - Soil type
  - Terrain
  - More can be added !

The Potential

- Suitability, accessibility, and zoning status are calculated for each of the active land-use classes
- Like in MURBANDY and MOLAND we calculate transition potentials for each cell from a set of suitabilities, accessibilities, zoning status and the neighbourhood effect
- The state for which a cell has the highest potential will be allocated to that cell
- However, there is the constraint that the number of cells in each state must be equal to the number demanded in that iteration

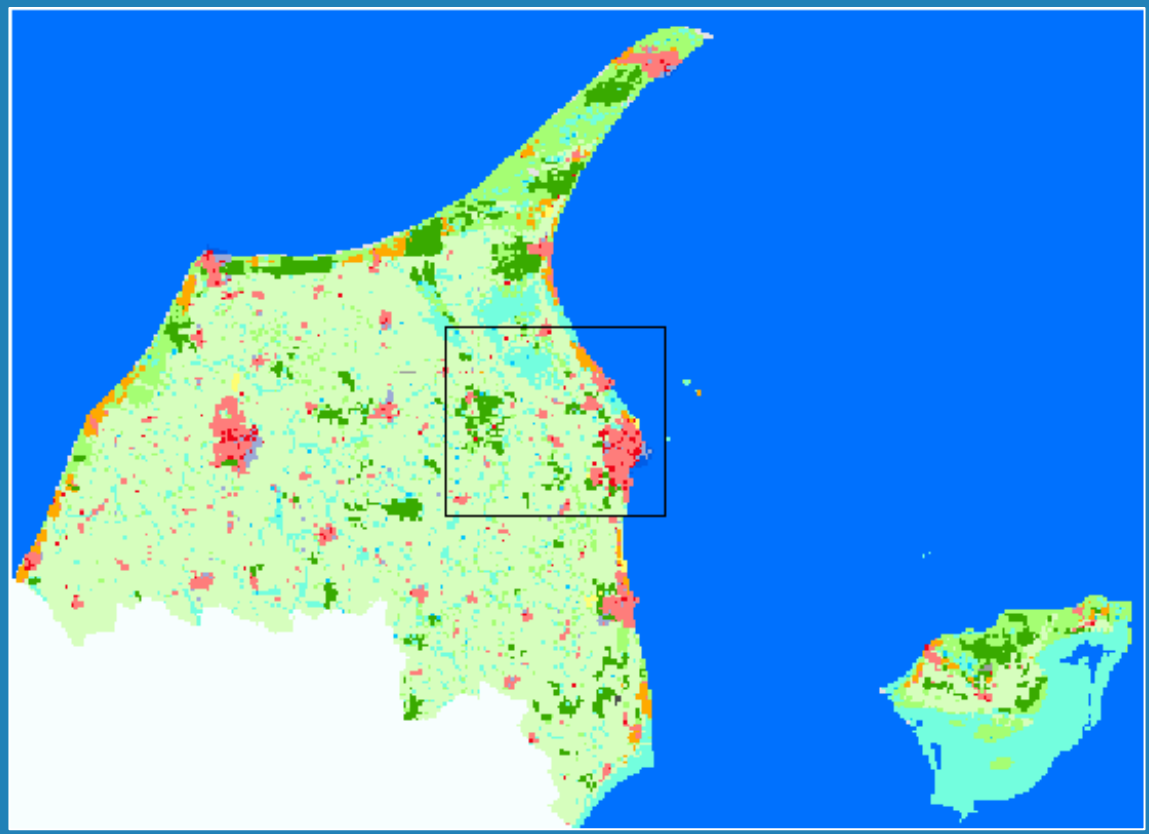
Implementation strategy

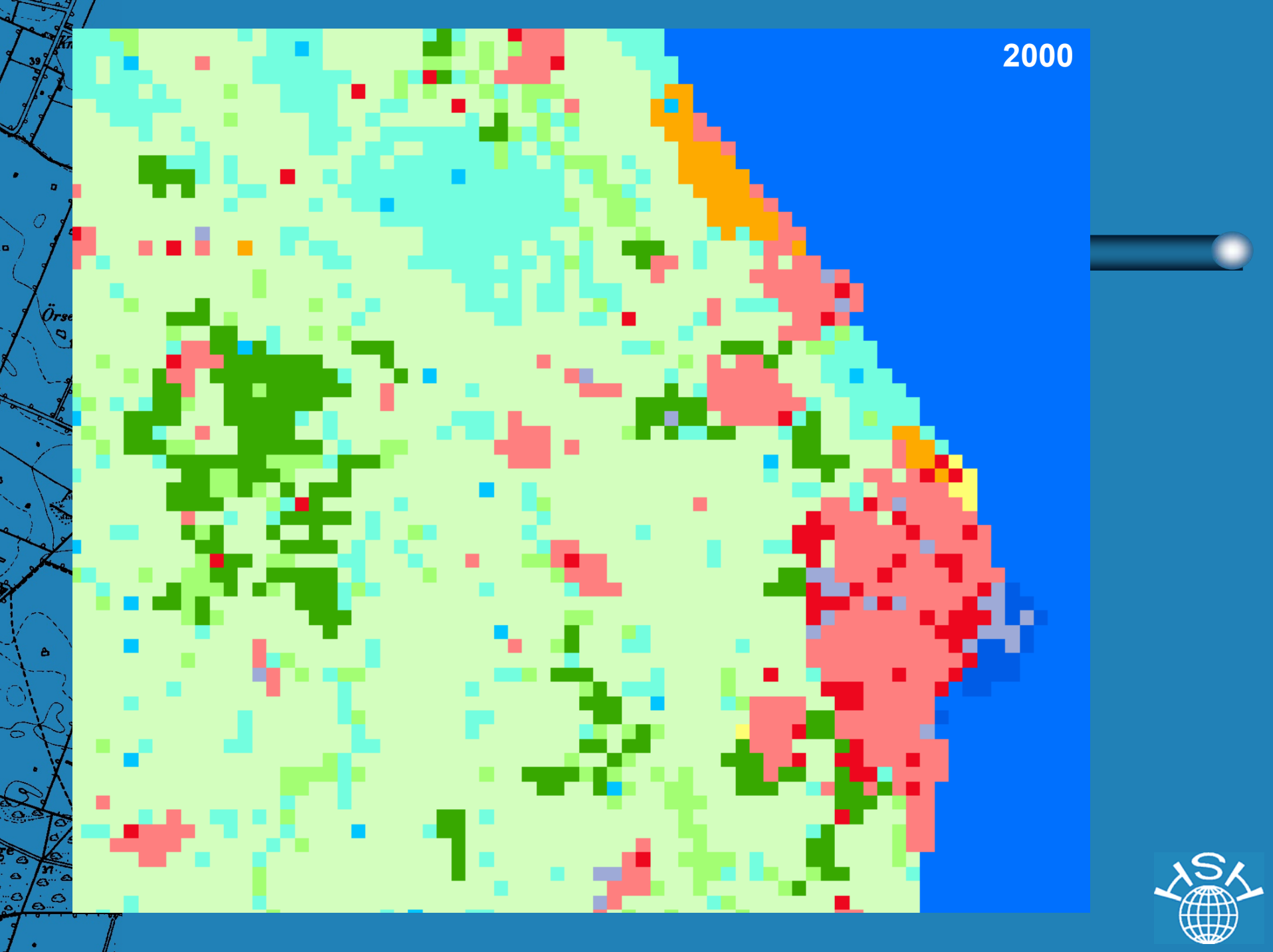
- Developed within the ArcGIS framework
- Programming language is Python

LUSIM05new.py

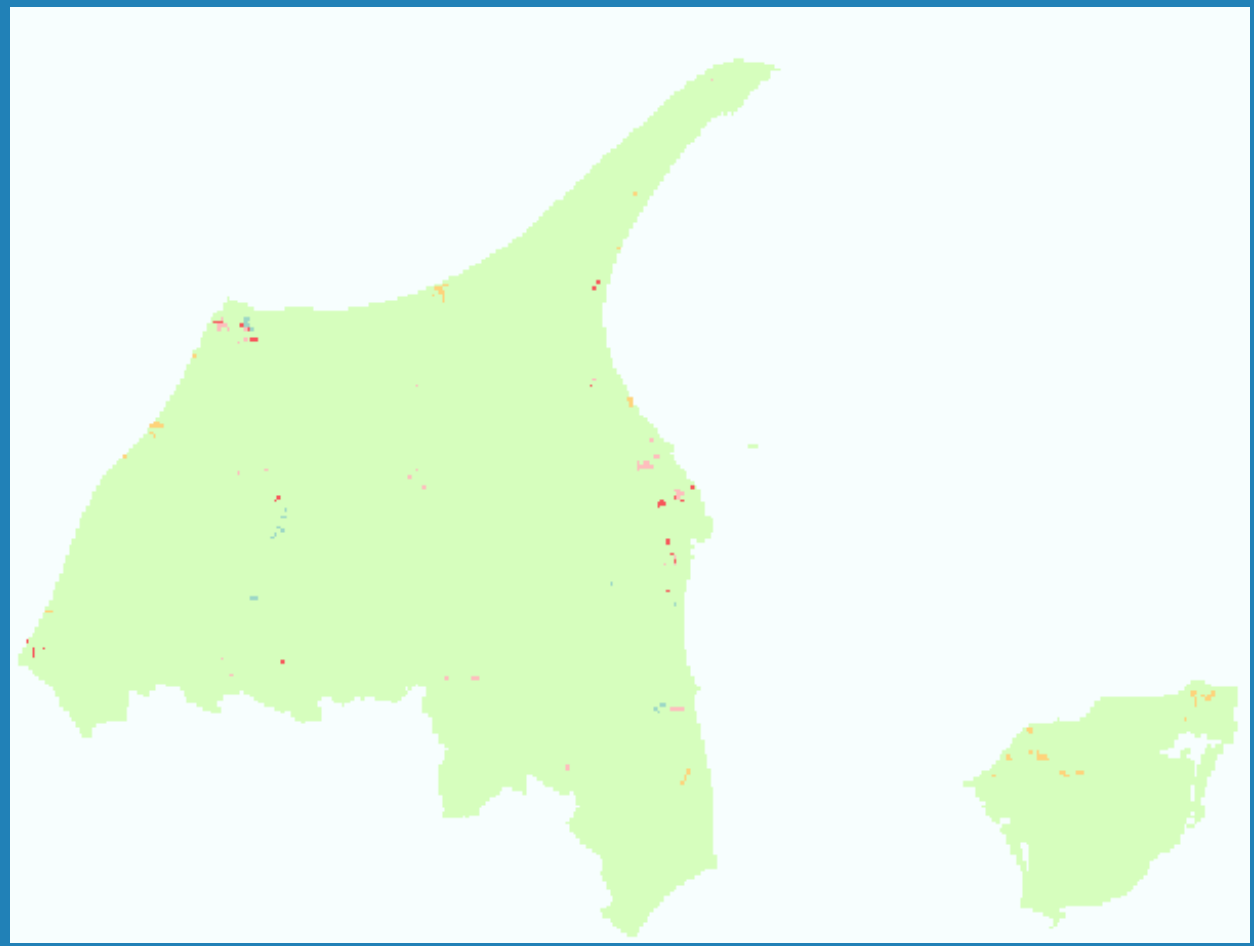
```
# ---------------------------------------------------------------------------
# LUSIM05.py
# Created on: on 30 September 2006
# Henning Sten Hansen
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, win32com.client

# Create the Geoprocessor object
GP = win32com.client.Dispatch("esriGeoprocessing.GpDispatch.1")
GP.SetProduct("arcview")

# Check out any necessary licenses
GP.CheckOutExtension("spatial")

# Load required toolboxes...
GP.AddToolbox("C:/Programmer/ArcGIS/ArcToolbox/Toolboxes/Spatial Analyst
# GP.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Spatial Ana
```

Land-use simulation 1990 - 2000

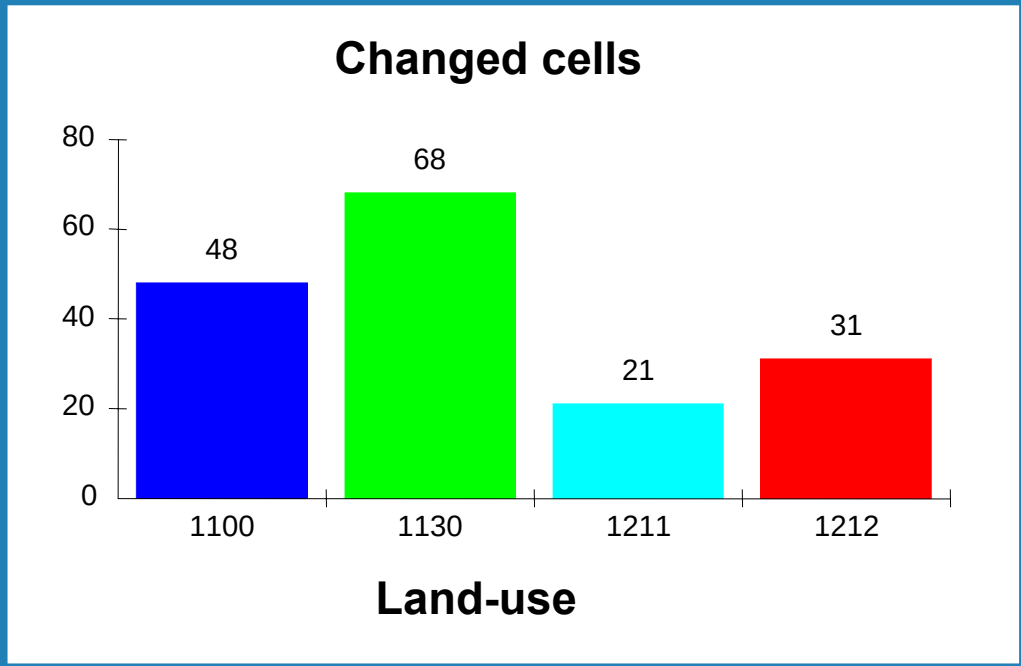



2000

Changed cells (1990 – 2000)



Changed cells



Concluding remarks

- The current model is our first attempt to develop a flexible and easy to use CA based land-use simulation model
- Pro
  - Easy to run various scenarios for different spatial planning efforts
  - Easy to change the number of land-use categories
- Cons
  - Time consuming to estimate the distance decay functions between various land-use categories
  - Difficult to calibrate the model against historical data due to uncertainties in as well the start year as the end year for the calibration period

Further research

- Develop more effective calculation procedures to reduce the calculation time
- Improve the calibration procedure
- Use the model in a practical Coastal Zone Management Project – Forum Skagerrak.

THANK YOU FOR YOUR ATTENTION ! ! !